Alignment Of The Fermilab D0 Detector

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ABSTRACT

The Fermilab D0 detector was used for the discovery of the top quark during Run I in 1996. It is currently being upgraded to exploit the physics potential to be presented by the Main Injector and the Tevatron Collider during Run II in the Fall of 2000. Some of the essential elements of this upgrade is the upgrade of the Solenoid Magnet, the Central Fiber Tracker, the Preshower Detectors, the Calorimeter System, and the Muon System. This paper discusses the survey and alignment of the these detectors with emphasis on the Muon detector system. The alignment accuracy is specified as better than 0.5mm. A combination of the Laser Tracker, BETS, and V-STARS systems are used for the survey

1. INTRODUCTION

The D0 experiment at the Fermilab Tevatron proton-antiproton collider is a general purpose collider detector experiment, built to study proton-antiproton collisions at the center-of-mass energy of 1.8 TeV. It is one of two collider detectors at Fermilab (Figure 1). The D0 detector is currently being upgraded. The goal of the D0 upgrade is to exploit the physics potential to be presented by the Main Injector and the Tevatron collider during Run II [1]. The D0 detector consists of several systems, such as the Solenoid Magnet, the Central Fiber Tracker, the Preshower Detectors, the Calorimeter System, the Muon System, etc. An overall view of the D0 detector is shown in Figure 2 with the primary detector systems indicated.

2. THE FERMILAB D0 DETECTOR

2.1 The Calorimeter System

One of the salient components of the D0 detector is a highly stable, liquid argon calorimeter. It consists of three units, the Central Calorimeter (CC), and the two End-cap Calorimeters (EC) (Figure 3).

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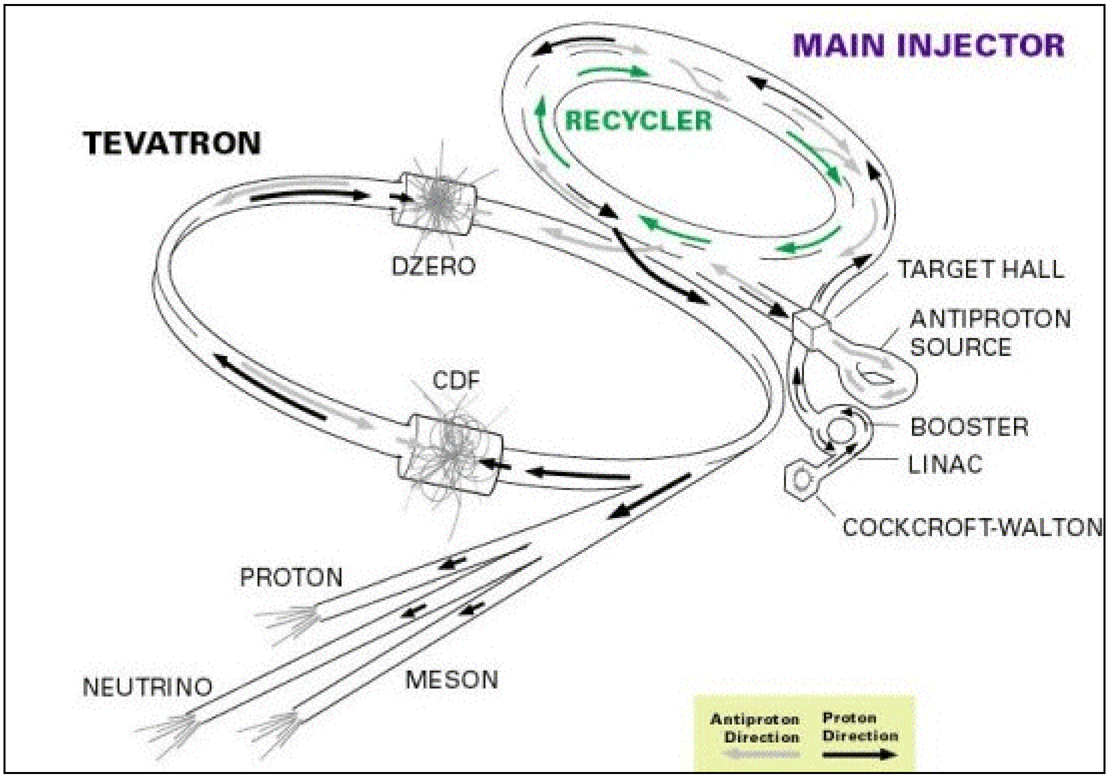

Figure 1. Fermilab's Accelerator Chain

2.2 The Solenoid Magnet

The solenoid is a 2 Tesla superconducting solenoid magnet. It is the first thin solenoid for a particle physics detector which operates at 2 Tesla. The system, consisting of a magnet cryostat, control dewar, and service chimney which interconnects the two (Figure 3). After the new central preshower detector was installed on the outer diameter of the magnet cryostat, the magnet and preshower detector were installed into the center bore of the existing Central Calorimeter cryostat.

2.3 The Forward Preshower (FPS)

The FPS is located in front of each End-cap Calorimeter (EC). It consists four scintillator layers numbered from 1 to 4, starting with the layer closest to the interaction point. Each layer consists of 8 sectors and each sector has four K+E targets that were referenced by CMM (Figure 2).

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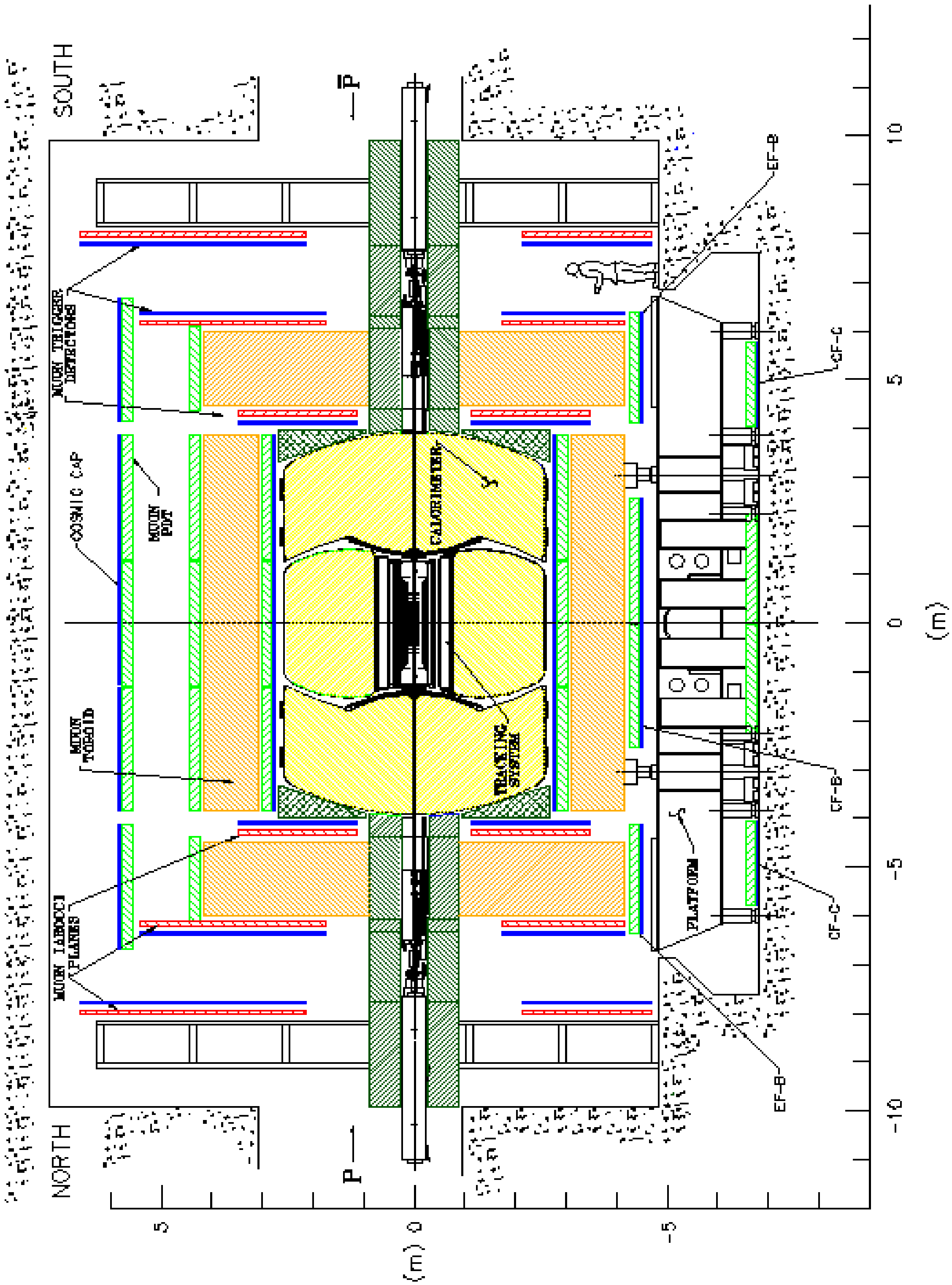

Figure 2. Side view of the D0 upgrade detector

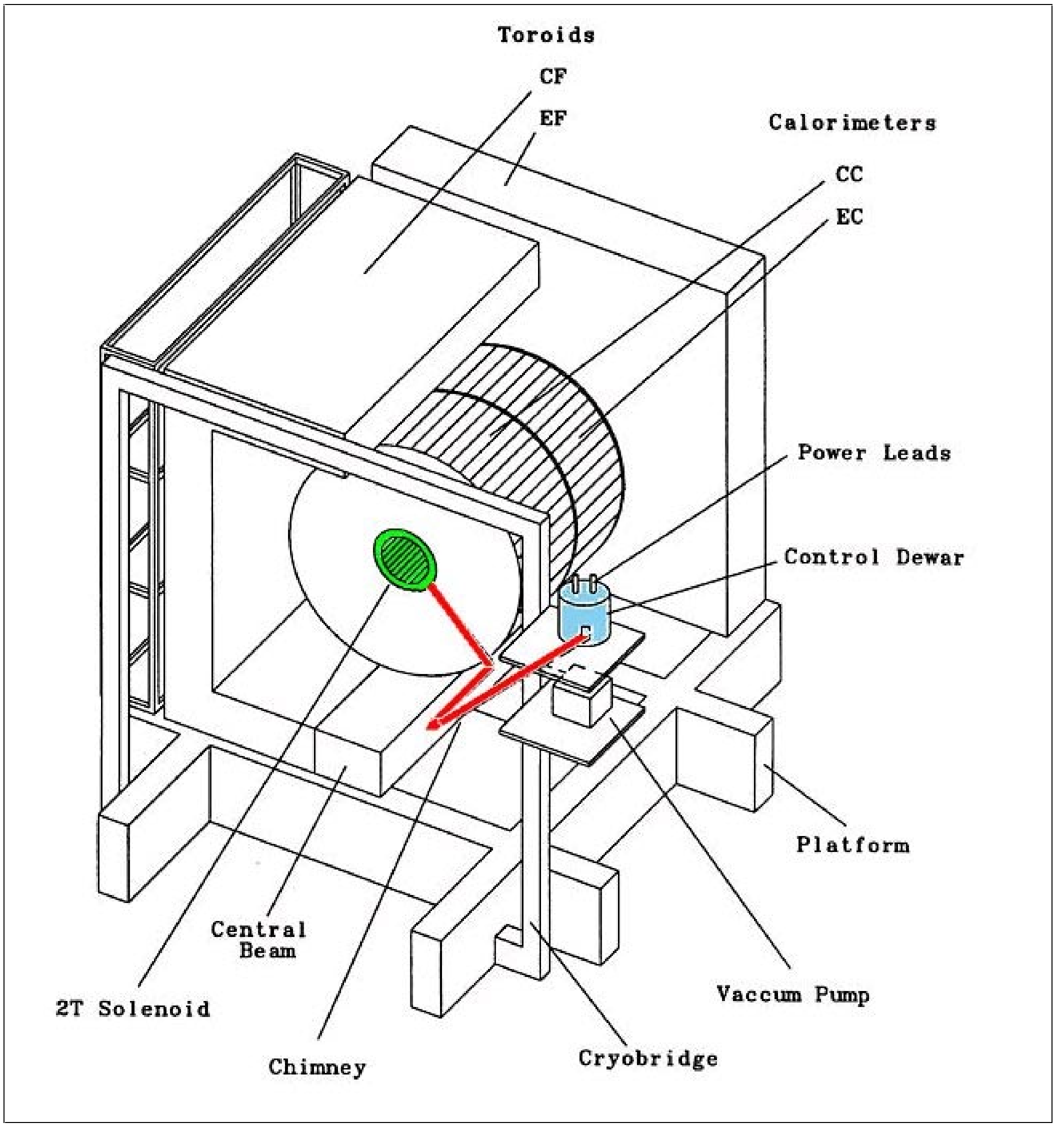

Figure 3. Three-dimensional view of the D0 detector

2.4 The Central Fiber Tracker (CFT)

The CFT consists of scintillating fibers mounted on eight concentric cylinders (Figure 4). It is located inside the Solenoid magnet in the Central Calorimeter (CC). The fibers are double clad and are 835 microns in diameter.

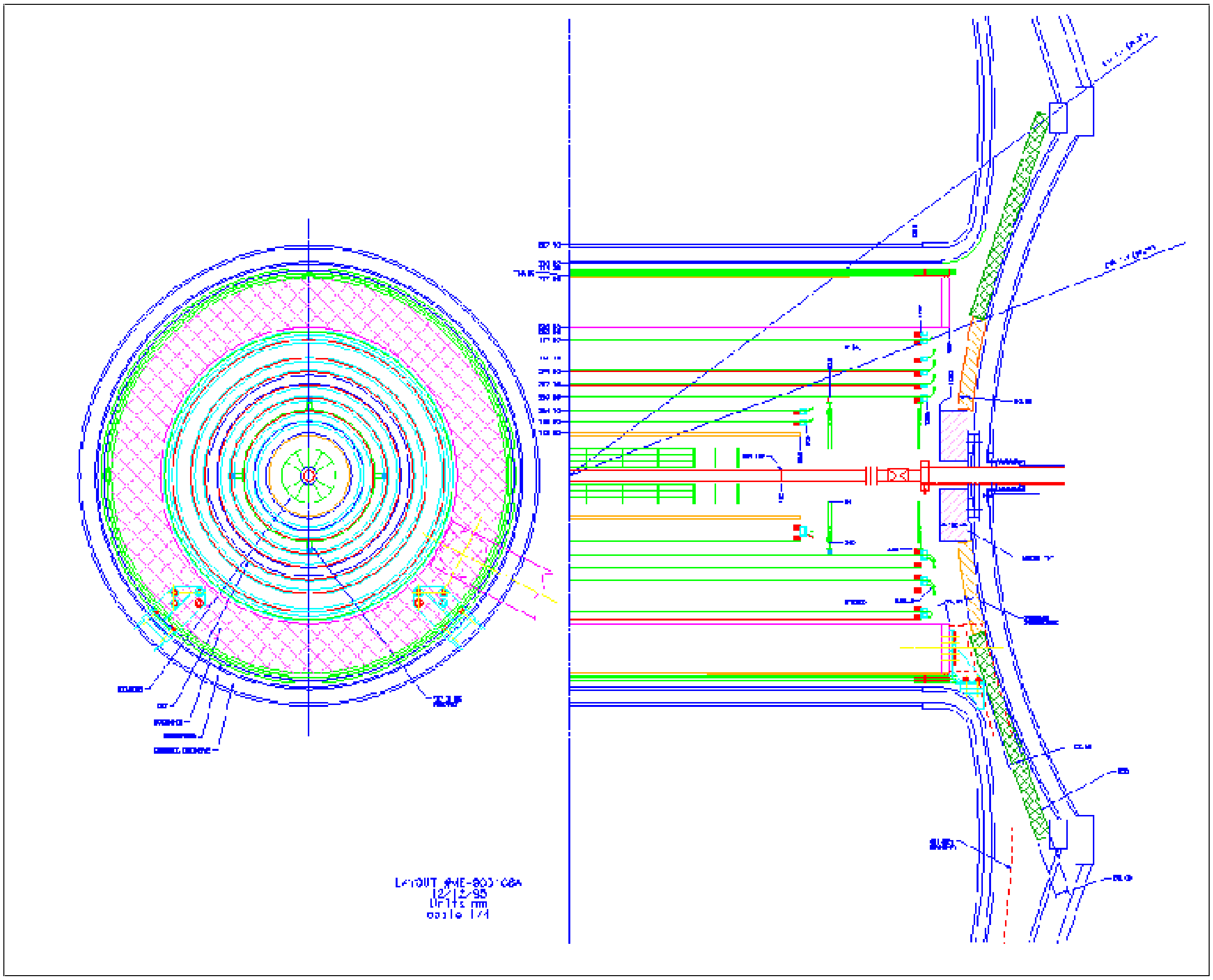

Figure 4. The Central Fiber Tracker and the Forward Preshower

3. THE D0 MUON SYSTEM

The design of the upgraded D0 muon system is driven by the D0 Run II physics goals and by the higher event rates and background expected in Run II. The upgraded muon system for Run II has three layers. The three layers are designated A, B, C, where the A-layer is closest to the interaction region and a toroid magnet is located between the A and B layers. Contained in these layers are the three basic subsystems of the upgraded muon system which include the Proportional Drift Tube (PDT) chambers, the Mini-Drift Tubes (MDTs) and the Scintillation Counters.

The muon system consists of two detectors: the central muon detector and the forward muon detector. The toroid magnet in the central muon detector is sometimes referred to as the central toroid magnet or CF iron. The toroid magnet in the forward muon detector is sometimes referred to as the forward toroid magnet or EF iron.

3.1 The Central Muon Detector

The central muon detector consists of a toroid magnet, large PDT drift chambers, the C-layer counters, the CF Bottom B- and C-layer counters, the EF Bottom B-layer counters, and the A-layer scintillation counters. The toroid magnet, PDT chambers and C-layer counters were used in Run I. The B- and C-layer Bottom and A-layer scintillation counters are added for Run II. No survey is required for the C-layer Counters, the B- and C-layer Bottom Counters, and A-layer scintillation counters. The mounting system ensures that the counter relative position are fixed to within about 1/8” (3 mm). After installation, the position of each counter is measured to 0.125 inch (3 mm) accuracy.

3.1.1 Central Toroid Magnet

The central (CF) toroid magnet, Figure 2, is a square annulus 109 cm thick weighing 1973 metric tons. It is built in three sections in order to allow access to the inner parts of the detector. The center-bottom section is a 150 cm wide beam, fixed to the detector platform, providing base for the calorimeters and tracking chambers. It is called the center beam (CB). To complete the toroid, there are two C-shaped sections (east and west CF toroid), which can be moved perpendicular to the center beam.

3.1.2 PDT Chambers

The PDT chambers provide measurements for all muons traversing the central toroid magnet or the outer edge of the forward toroid magnet. The PDT chambers consists of three layers of drift chambers, one layer inside (A) and two layers (B and C) outside the central toroid magnet. Approximately 65% of the central region is covered by three layers of PDTs, close to 90% is covered by at least two layers. The PDT chambers are constructed from rectangular extruded aluminum tubes and are of varying size with the largest being approximately 100 x 225 in^2. The PDTs outside the toroid magnet (B- and C-layers) have three decks of drift cells and the layer inside the toroid (A-layer) has four decks with the exception of the bottom PDTs (these have 3 decks). The cells are 10.1 cm across, with typically 24 columns of cells per chamber. The

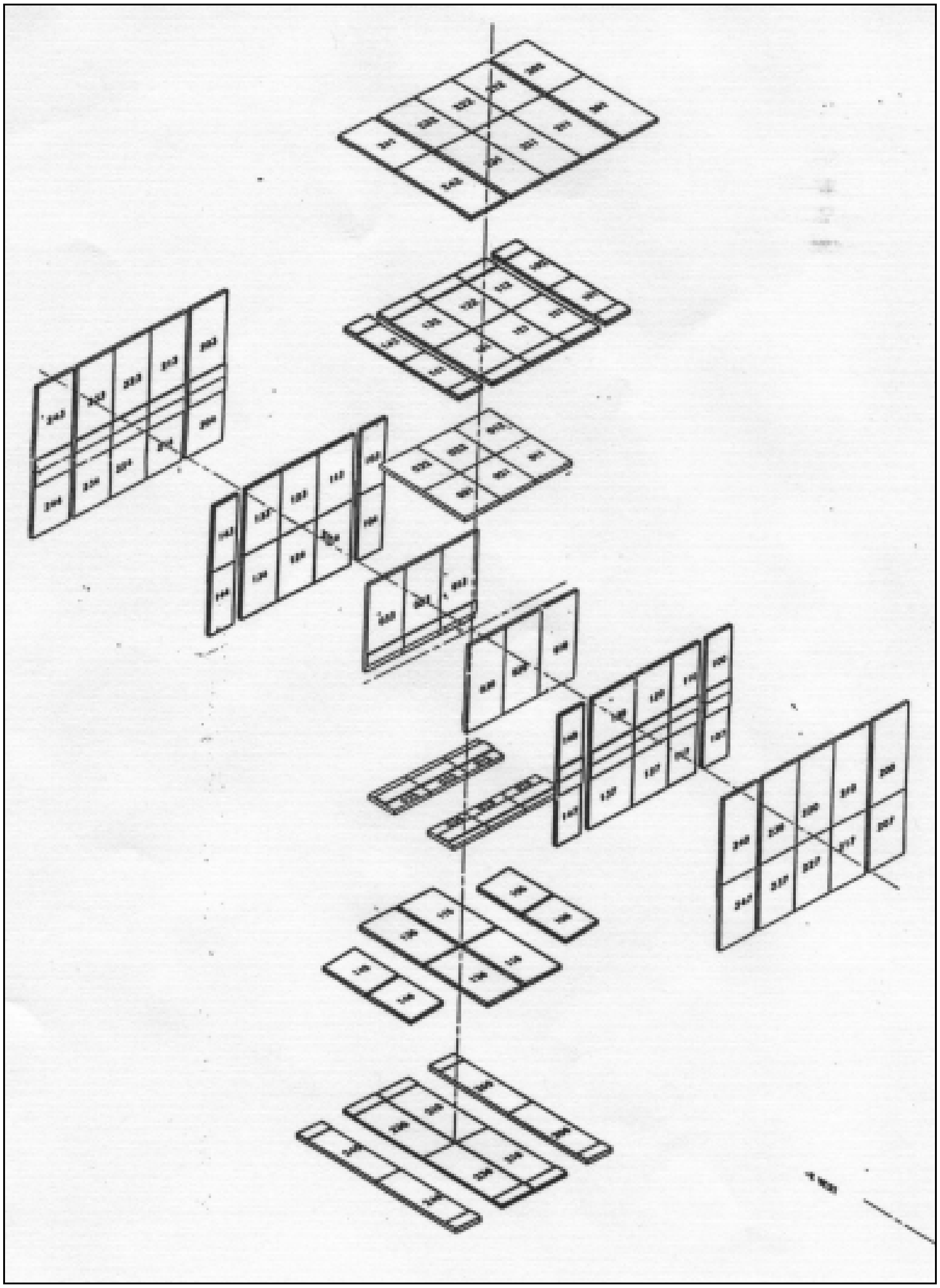

Figure 5. The layout of the PDT chambers.

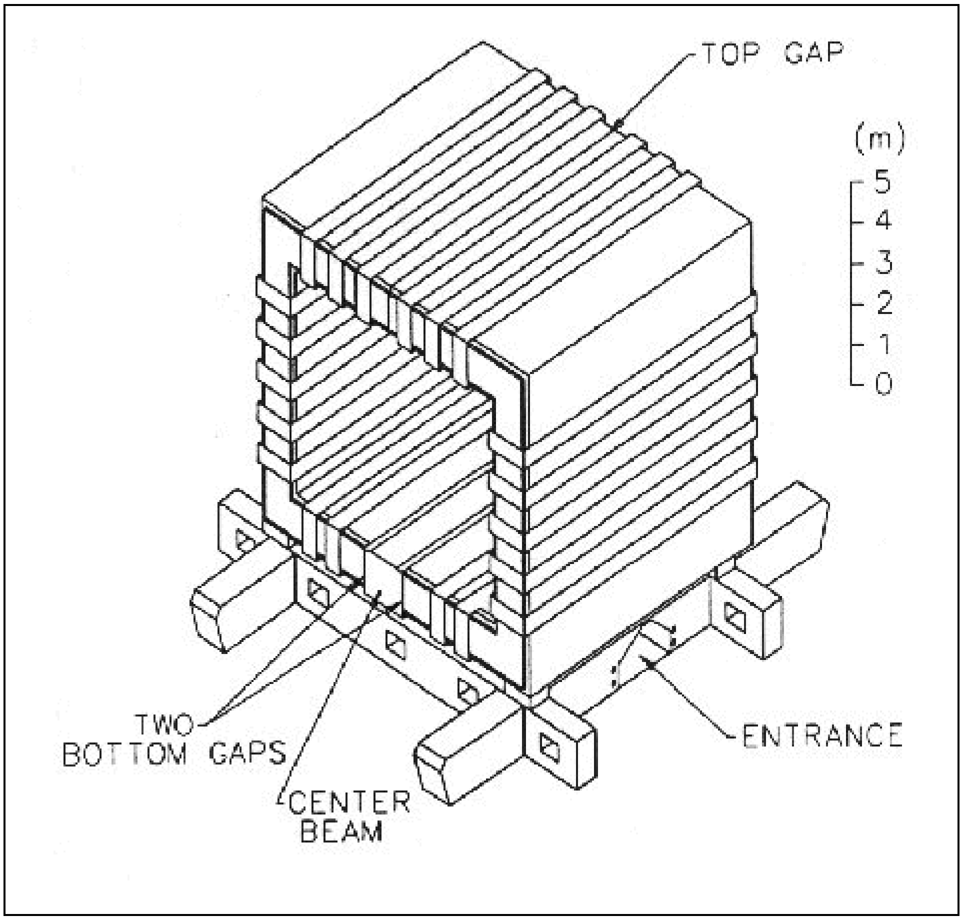

Figure 6. View of the central muon toroid showing the coils, the Center beam, and the seams for opening and closing the detector.

chamber wires are oriented along the toroid magnetic field direction to provide the position of the bend coordinates for the muon momentum measurement. Figure 5 shows the layout of the PDT chambers.

3.2 The Forward Muon Detector

The forward muon detector consists of a toroid magnet, three layers of Mini-Drift Tubes (MDTs) for muon track reconstruction, and three layers of Scintillation Pixel Counters for triggering on events with muons. The forward muon detector is contained in two sections, the North and South sections of the detector.

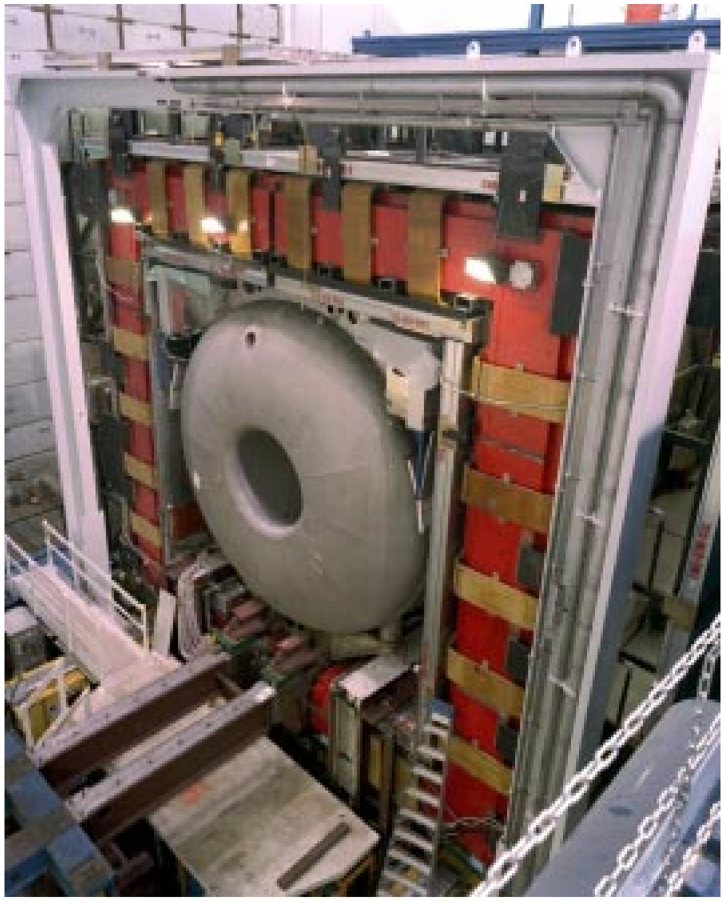

Figure 7. Muon Detector showing CF Toroid surrounded by PDT chambers.

3.2.1 Forward Toroid Magnet

The forward (EF) toroid magnet is 63 inches thick. There are two sections of the EF magnet, one in the North end and one in the South end of the forward region.

3.2.2 Mini-Drift Tubes

The mini-drift tubes are arranged in three layers (A, B and C) that consist of three (B and C-layers) or four (A-layer) planes. The A- layer is near the inner surface of the toroid magnet, the B-layer is near the outer surface of the magnet, and the C-layer is the most distant from the center of the detector (Figure 2). The planes are made up of several tubes. An individual tube has eight cells, each with a 9.4x9.4 mm^2 internal cross section with a 50 micron anode wire in the center. The accuracy of wire position within a tube is 160 microns. Figure 8 shows one complete MDT plane.

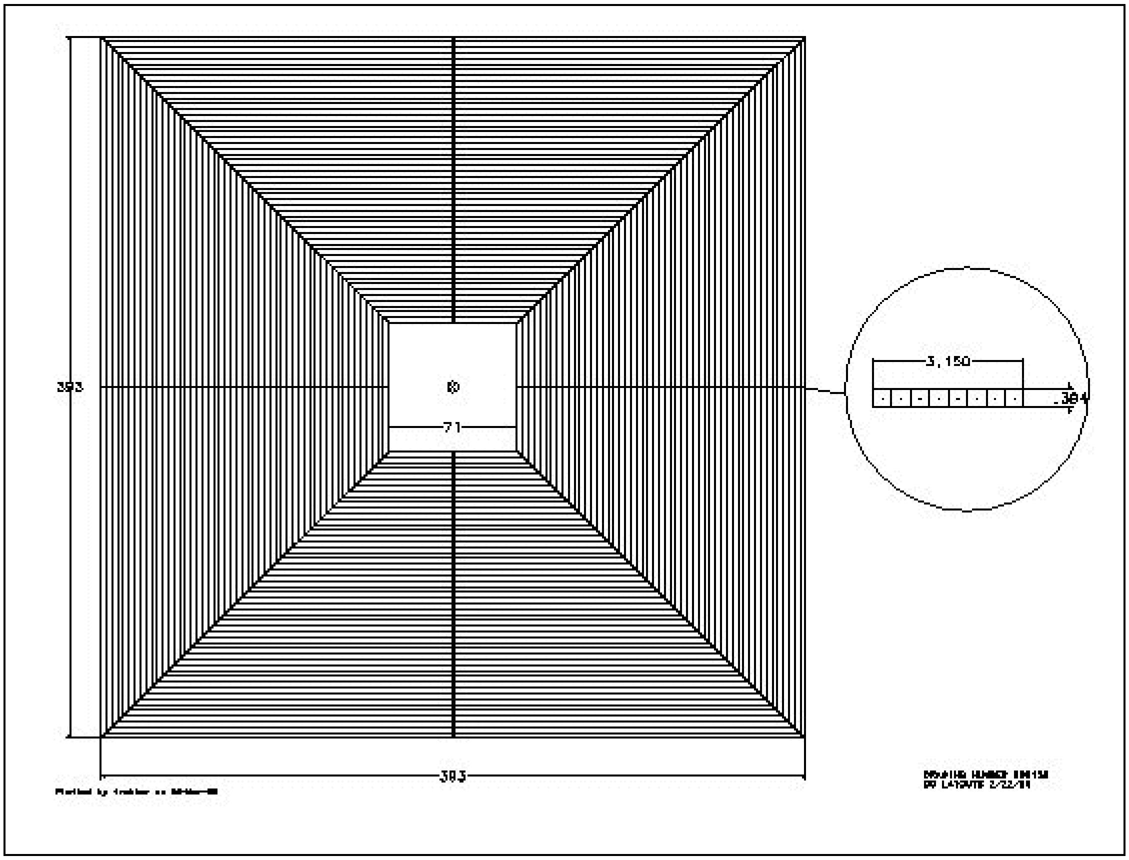

Figure 8. Mini-Drift Tubes: individual 8 tube module and one complete plane.

Each layer is divided into 8 octants. Each octant contains tubes of different lengths and is an independent assembly unit. The A-layer has a cut in the two bottom octants to accommodate the calorimeter support. The bottom octants of layers B and C are shorter than others because their size is restricted by the collision hall floor. Layers A and B are mounted directly on the EF toroid. The C-layer will be mounted on the EMC (End-iron Muon Chamber) support structure. The tubes are oriented along the magnetic field lines. Each octant is assembled and tested separately, then moved to D0 for assembly into planes.

3.2.3 Scintillation Pixel Counters

There are three layers (A-, B- and C-layers) of scintillation counters on each side of the detector. The A- layer is the closest to the interaction region, then B-layer, and the C-layer is the most distant from the detector center. Each layer of counters is divided into 8 octants with 96 counters per octant. The size of the largest C-layer is 12x10 m^2. Each octant is assembled and tested separately, then moved to D0 for assembly into planes. Each plane of counters is mounted in the D0 detector with the support at the top of the frame and is movable along the beamline in order to get access to MDT planes [5]. The C-layer does not move. Figure 9 shows one quadrant of a scintillation pixel plane.

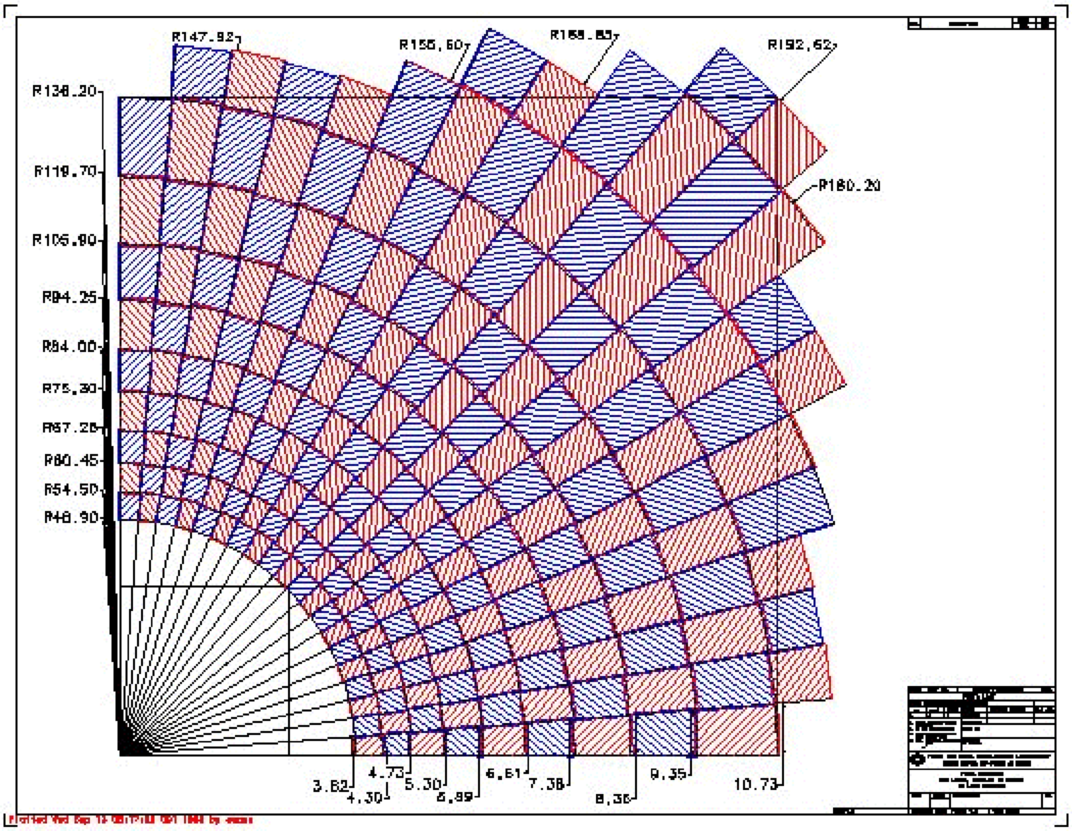

Figure 9. One quadrant of scintillation pixel plane

4. SURVEY OF THE D0 DETECTORS

4.1 D0 Global Coordinate System

The survey global coordinate system is a right-handed Cartesian coordinate system defined as follows:

Origin - Center of D0 Detector
X-axis - EAST axis. Positive to the right and perpendicular to the Y-axis
Y-axis - NORTH axis. Positive along the anti-proton direction
Z-axis - Positive up and perpendicular to both X- and Y-axes.

4.2 Control Points

Since the Center Beam (CB) is fixed to the detector platform and the Central Calorimeter (CC), several reference markers have been established as control reference points on the CB and CC. Eight Eyeballs set in Lower and Upper Prism mount at SW, SE, NW, and NE corners of CB stationary platform are used to define the D0 Global Coordinate System. Fourteen Tooling balls (7 in each north and south) were mounted ton the CC and referenced to the CB. The survey markers on the North EC (ECN) are defined by eight (8) Eyeballs in mount on the four (4) legs of ECN, two on each leg. The survey markers were referenced to the CB when both ECs were in the closed state.

Several points have also been established on the CF toroid magnet. These points have been measured with the CF toroid magnet opened in the east-west direction and with the magnet in the closed position. In the magnet closed position, these points were also measured with the toroid magnet ON and OFF. The coordinates of all the measured points were transformed into the D0 global coordinate system. Additional control points have been added on the trusses between the B- and C-layers outside the CF toroid magnet. More reference markers were added as control points on and around the EF toroid magnets on both sides of the detector. There are several types of reference markers used for control points which include 2x2 in^2 construction plates, with 0.25 inch holes in the center, welded to the magnet. On the CF toroid magnet, a 4 inch long pedestal with 1.5 inch diameter and 0.25 inch hole in the center is used. A 12 inch long pedestal was used for the EF toroid magnet. Some of the K+E targets used for Run I are also used as control points.

4.3 Survey Methods

The Laser Tracker, SMX Tracker4000 and its associated software Insight™ are used for establishing control points. The Laser Tracker is a device that makes three-dimensional measurements. It uses a laser distance meter, two precision angle encoders and a proprietary software to calculate, store and display the real-time three-dimensional position of a mirrored target situated over the desired point or feature. The Laser Tracker is used to establish most of the control points.

The V-STARS system is a portable non-contact, three-dimensional digital photogrammetric system. The system consists of one or two digital cameras and V-STARS software. To measure an object, the camera(s) are used to photograph the object from various directions. The digital images are processed immediately by the V-STARS software to provide three-dimensional coordinates and statistical information. The software is based on photogrammetric-bundle- triangulation methods. The V-STARS system is used to connect all the component points to the control points.

The BETS (Brunson Electronic Triangulation System) is a portable non-contact, three-dimensional coordinate measuring system. The system consists of precision electronic theodolites connected to a computer via Brunson cabling and a theodolite interface module. The computer has a Brunson software that can display real time three-dimensional coordinates and statistical information. The BETS system is used to connect all the K+E target and tooling balls used in Run I to the new control survey points.

4.4 Survey Requirements

The survey of the D0 muon detectors is being done in three phases for the PDT chambers, the MDTs, and the Pixel Counters. Phase I is the initial survey and referencing of the individual components. Phase II is the measurement of the relative locations of the components on a common support. Phase III survey is used to determine the position of the components in the collision hall. The required accuracy for all phases is specified as better than 0.5 mm for the PDTs and the MDTs and better than 2.0 mm for the Pixel Counters. No survey is required for the C-layer Counters, the B- and C-layer Bottom Counters, and the A-layer Scintillation Counters.

4.5 Survey of D0 Calorimeter

During Run I the BETS system was used to survey the points on the CB. For Run II, Tooling balls on the CC and the survey markers on the legs of the EC were surveyed with the Laser Tracker using the CB Prism mounts as reference. Surface profiles of the North and South faces of the CC done with V-Stars.

Eight additional plates with 0.250 inch holes were mounted the ECN (4 inside and 4 outside). The ECN markers, the beam pipe location, and the 4 outside plates were surveyed with the Laser Tracker using the CB Prism mounts as reference. The beam pipe location on the inside the EC and the 4 inside plates were surveyed with V-Stars. Same survey is repeated for the South EC (ECS).

4.6 Survey of D0 Solenoid Magnet

There are twelve 0.250 inch holes (6 in each North and South) drilled on the surface of the Solenoid magnet as survey markers. These holes were initially referenced to the center of the Solenoid magnet with the Laser Tracker. After the Solenoid was inserted into the center bore of the CC, the survey markers were surveyed using the Tooling balls on the CC as reference. All Solenoid re-surveys were done with V-Stars.

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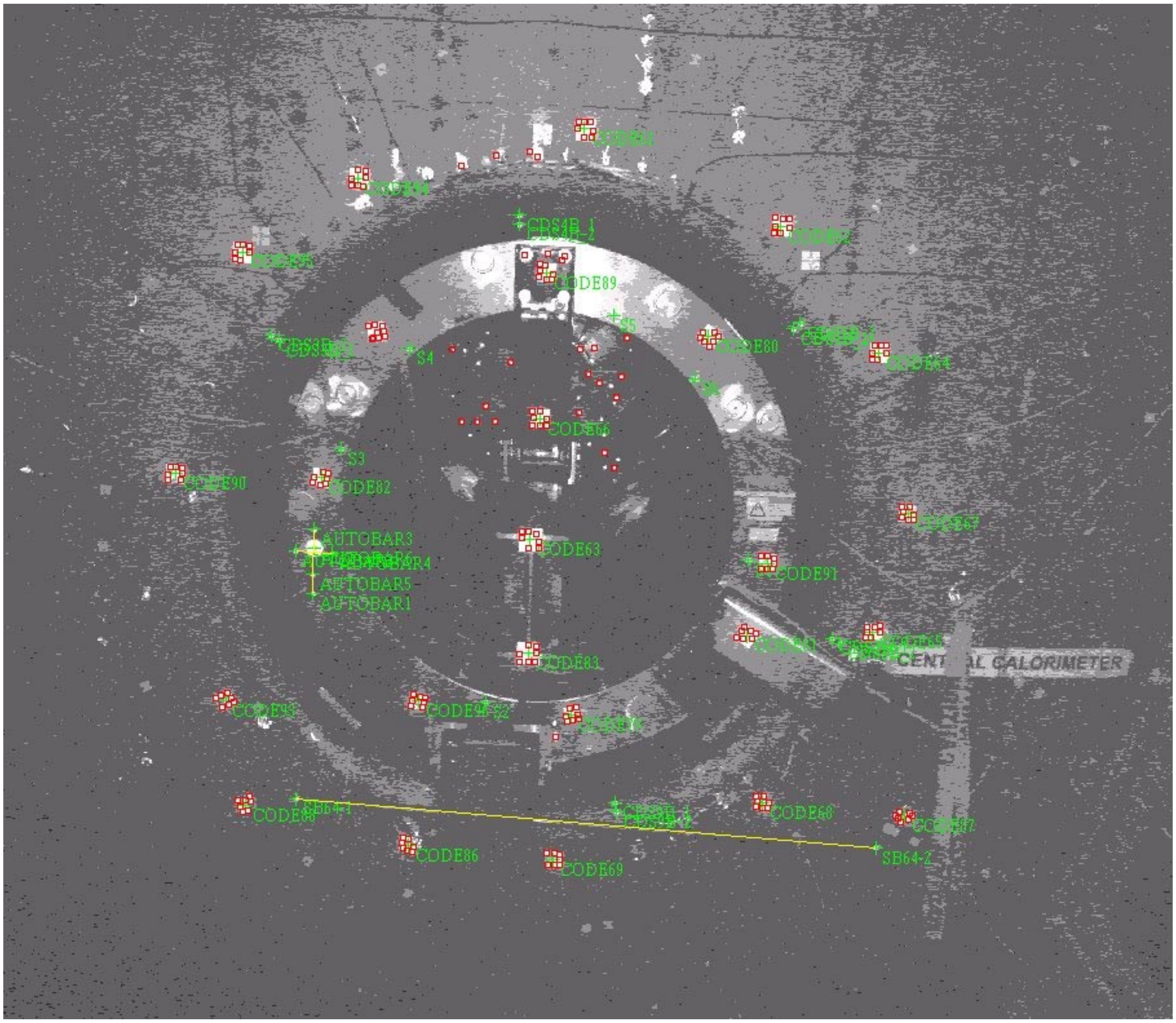

Figure 10. Solenoid and Central Calorimeter Survey

4.7 Survey of Forward Preshower (FPS)

The main hanging frame south FPS was centered around the beam pipe on the surface of the ECS using the Laser Tracker. There are four layers of FPS. Each layer consists of 8 sectors and each sector has four K+E targets that were referenced by CMM. Four 6mm V-Stars adhesive targets were place next to the K+E targets. All 32 targets have been measured to the referenced K+E targets by CMM. Each layer was surveyed with V-Stars using the 4 inside plates on the ECS. After layer #1 was surveyed, layer #2 was mounted on top of layer #1 and the surveyed. Same procedure for layers #3 and #4. Same survey is repeated for the North EC (ECN).

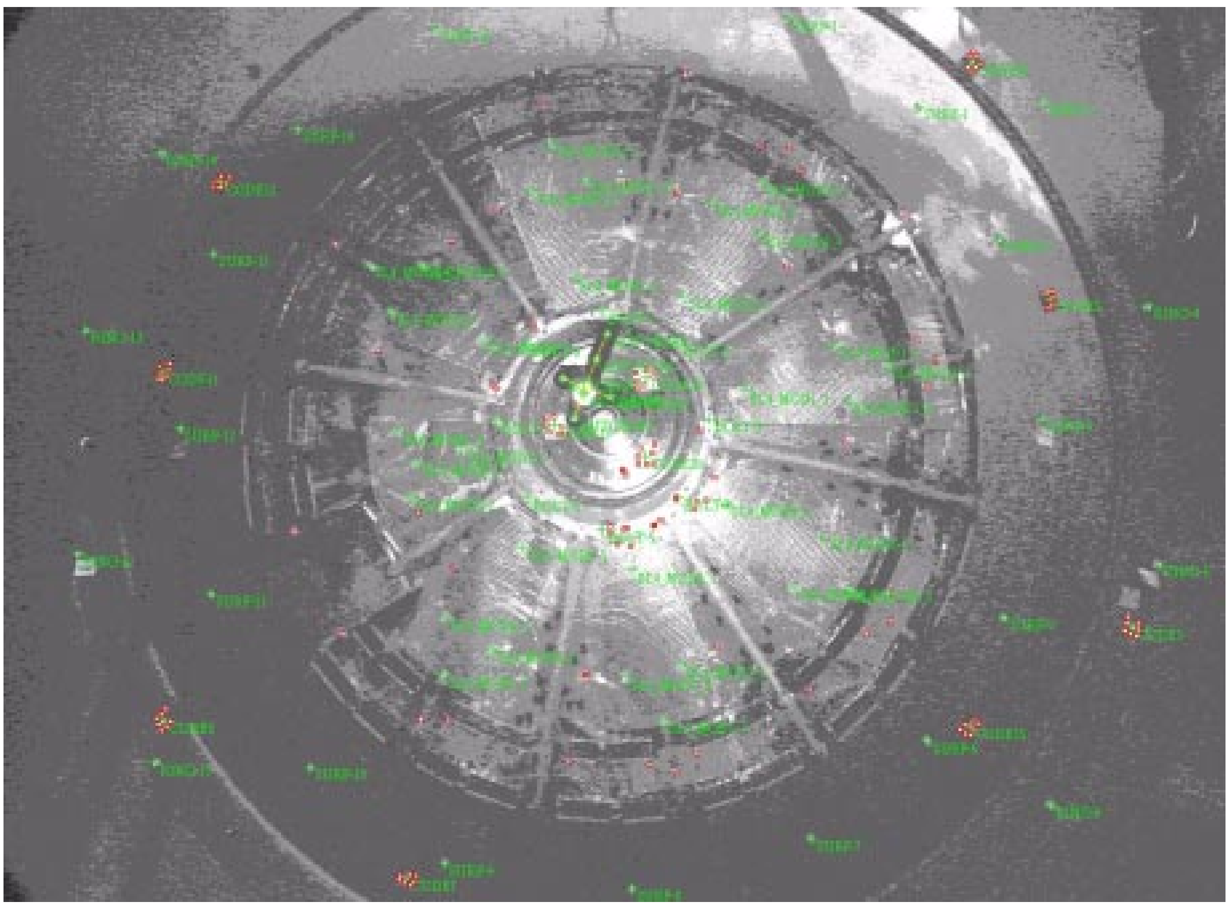

Figure 11. Forward Preshower Layer 4 Survey

4.8 Survey of Central Fiber Tracker (CFT)

Twelve 6-inch pedestals (6 in each North and South) with 3 mm V-Stars target were mounted on the surface of the CFT and were initially referenced with V-Stars. The targets were also measured with CMM. After CFT was placed inside the Solenoid, the pedestals were surveyed with V-Stars using the Tooling balls on the CC as reference and the holes on the Solenoid magnet.

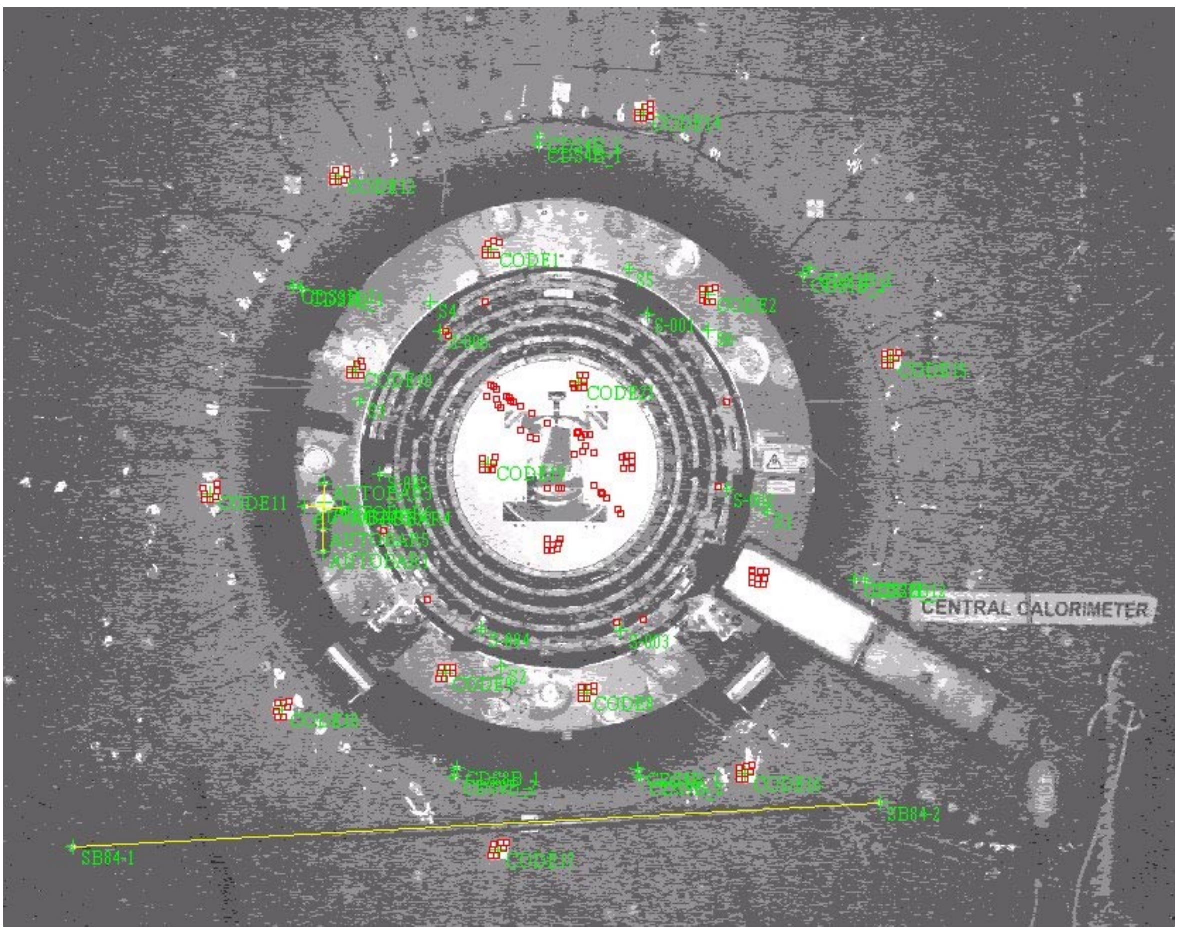

Figure 12. CFT and Solenoid Survey

4.9 Survey of D0 Muon Detector

4.9.1 Phase I Survey

4.9.1.1 PDT Survey

The Phase I survey is the referencing of the new bushing holes and old tooling balls on the PDT relative to the wire position. Each PDT chamber has two end plates with precise holes which locate the sense wires. Drilled in each plate are two 0.25 inch diameter alignment reference holes. The position of all the sense wires relative to these four reference holes is known from the PDT chamber design and construction technique. The reference holes are usually covered up when the PDT chambers are installed. Therefore, four 0.25 inch diameter bushing holes (eight for the C-layer chambers) were drilled near the corners of the chamber. On some chambers, 0.50 inch diameter tooling balls are mounted near the corners. For the A-layer the holes were drilled into 0.50 x 0.50 in^2 stainless steel bars attached to the sides of the PDT channel extrusions. There are 3 or 4 holes per bar, two on top near each end, one on the end of the bar, and one on the side for some bars. The Laser Tracker was used to measure the relative position of the reference holes and the bushing holes on each of the PDT chambers. In addition to the bushing holes, the locations of the old Run I tooling balls were measured for comparison with Run I measurements.

All of the Phase I survey of the PDT chambers have been completed for all the A-, B-, and C-layers. Five already installed PDT chambers were surveyed with the V-STARS system. The required accuracy for the Phase I survey is specified as better than 0.5 mm.

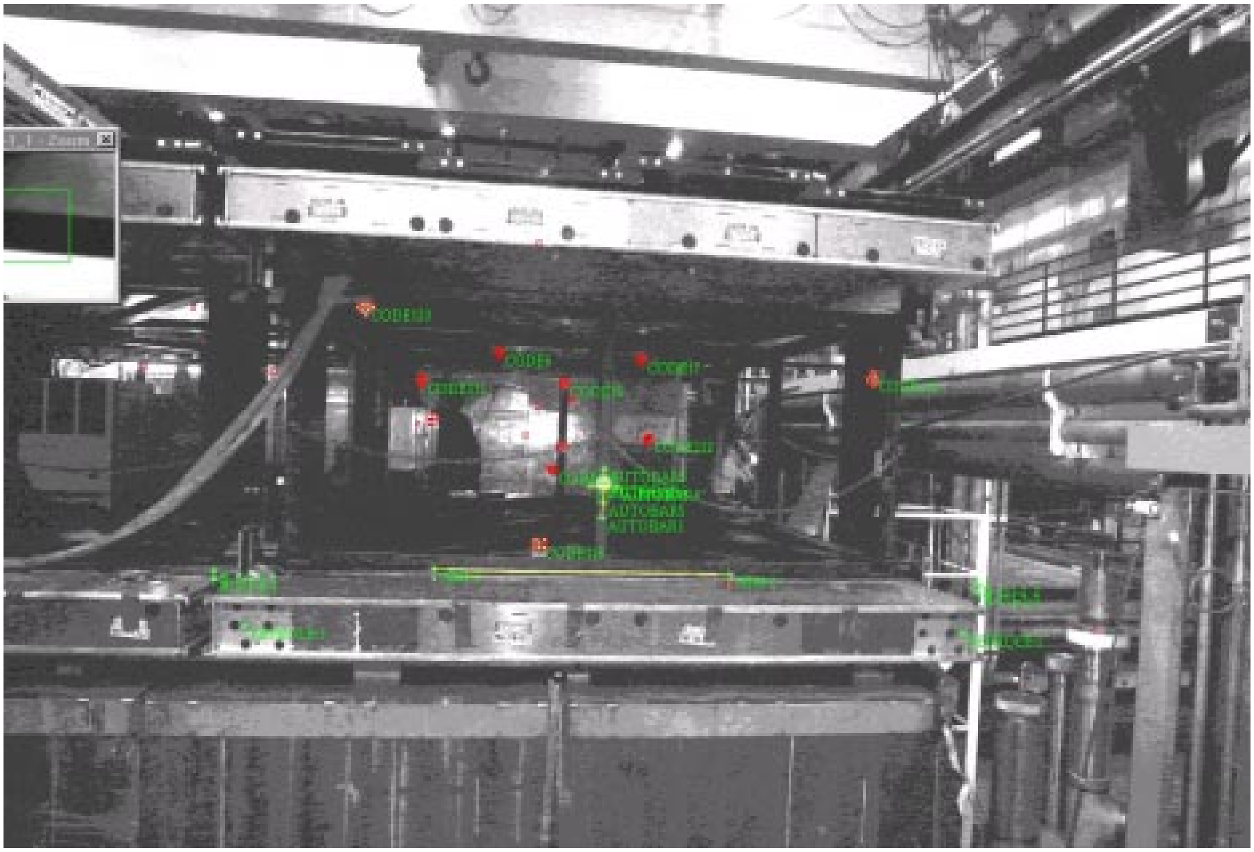

Figure 13. Phase I PDT Survey

4.9.1.2 MDT Survey

There are a total of 48 MDT octants, 8 in one octant plane. Each octant has four 0.25 inch bushing holes drilled on the front side of the octant. For the MDT modules, the supports are installed using a precision jig to drill holes for rivets which positions the counter support. Individual MDTs are mounted on both sides of the octant. The V-STARS system is used for the Phase I survey. The survey is used to check the accuracy of placement for a small sample of the octants to insure that that the drilling system is working properly. Three adhesive reflective V-STARS targets are carefully placed on every second MDTs on both sides of the octant. In addition, reflective targets are placed at each end of the individual MDTs. The location of the targets with respect to the bushings are measured with the V-STARS system. The model coordinates of the four bushing holes is known from the MDT octant design and construction technique. A transformation between the model coordinates and the measured coordinates yields the coordinates of the MDT points in the model coordinate system. The required accuracy for the Phase I survey is specified as better than 0.5 mm.

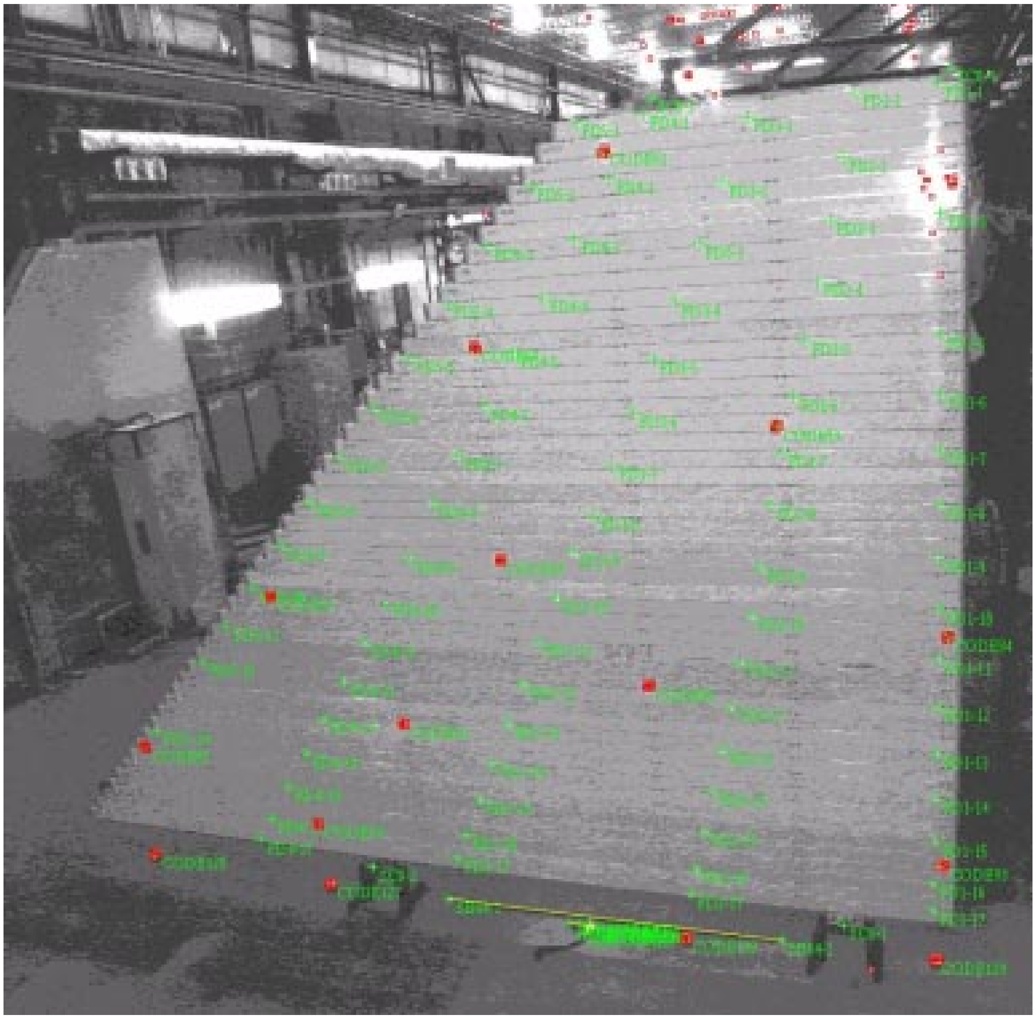

Figure 14. MDT Phase I Survey with V-STARS.

4.9.1.3 Pixel Counter Survey

The installation of scintillation counters into octants are done with accuracy of 2 mm. These accuracy is 1% or less of the counters size. There are a total of 48 Pixel Counter octants, 6 in each Pixel plane. Each octant has four 0.25 inch bushing holes drilled on the front side of the octant. Individual Pixel Counters are mounted on the front sides of the octant. The counters are held by supports which are installed using a precision jig for drilling holes to mount and locate the supports. The V-STARS system is used for the Phase I survey for a small sample of octants to verify the precision of the counter placements. Adhesive reflective V-STARS targets are carefully placed on the Pixel Counter grid along the 90° edge sector, along the Middle sector, and along the Diagonal sector. There are two targets per counter. The location of the counter grid with respect to the bushings are measured with the V-STARS system. The model coordinates of the four bushing holes are known from the Pixel Counter octant design and construction technique. A transformation between the model coordinates and the measured coordinates

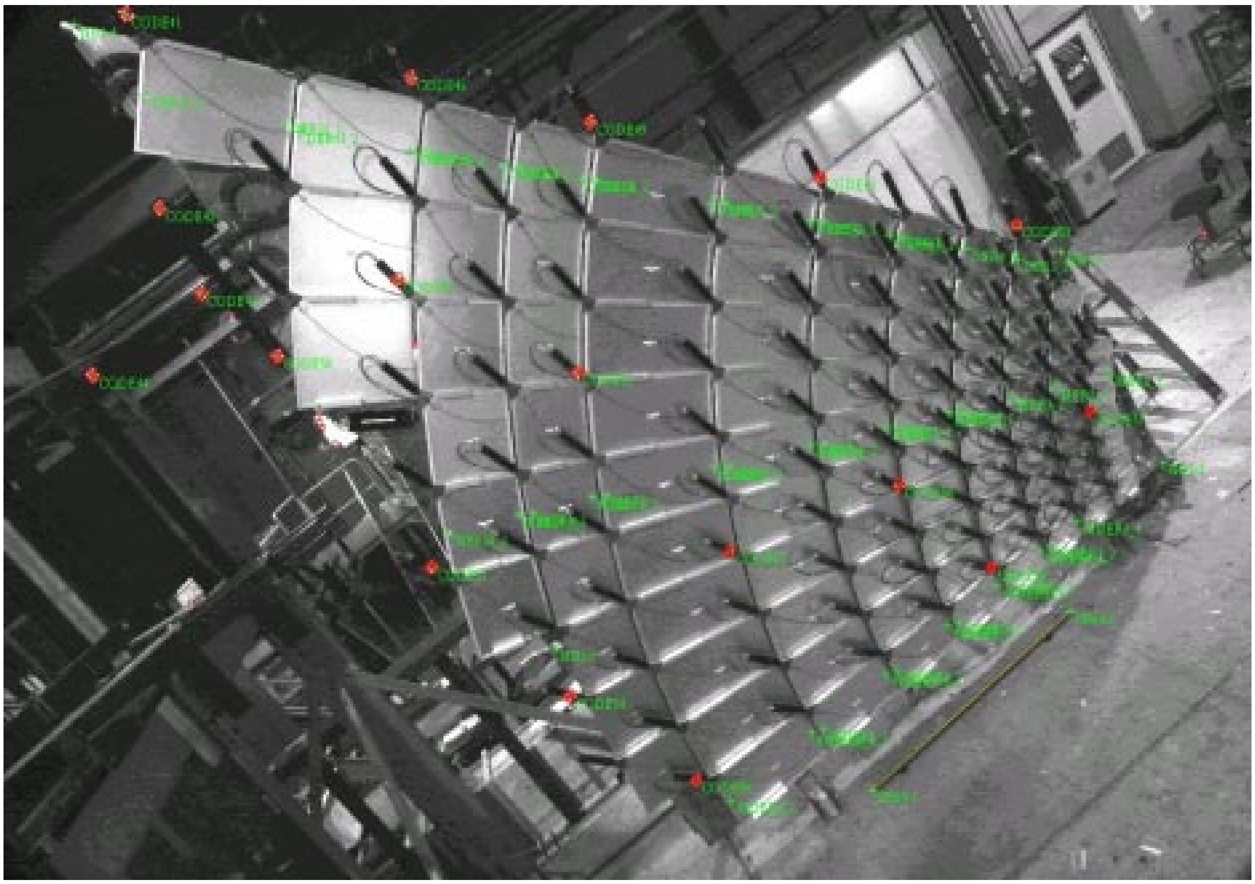

Figure 15. Scintillation Pixel Counter Octant with V-STARS.

yields the coordinates of the Pixel Counter points in the model coordinate system. The required accuracy for the Phase I survey is specified as better than 2.0 mm.

4.9.1.4 EMC Truss Survey

The EMC (End Muon Chamber) Truss is 40 foot high metal structure that will be used to hold the B- and C-layer MDT and the Pixel planes. It consists of two top and bottom halves.

There are fourteen 20 inch long pedestals (7 in Top half, 7 in Bottom half) mounted on the truss used as survey reference. Each pedestal has a 0.25 inch hole.

The top and bottom sections of the Truss were first assembled outside. The whole Truss was surveyed with the V-Stars at a certain temperature condition. The Truss was dismantled and moved indoor where the top and bottom sections were surveyed separately. The bottom Truss was also re-surveyed indoor when an iron shield is mounted and exercised (open and closed configuration). Temperature correction was applied.

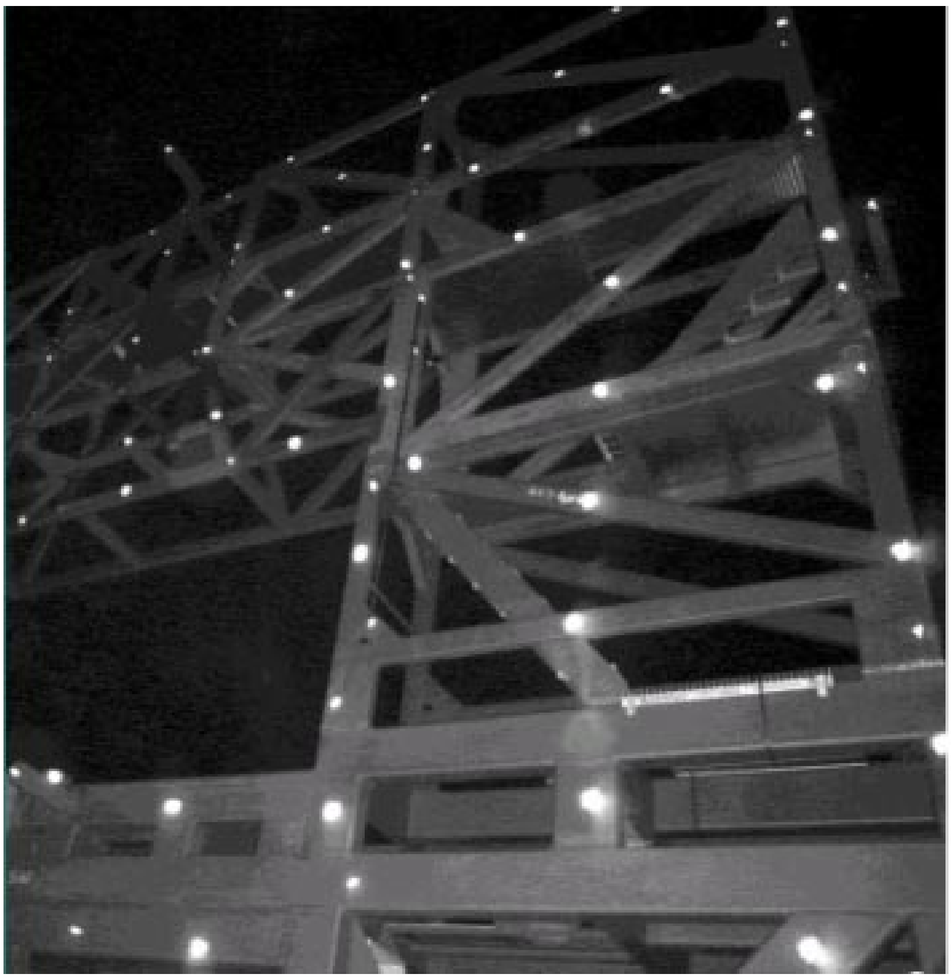

Figure 16. EMC Truss Night Survey with V-Stars

4.9.2 Phase II Survey

4.9.2.1 PDT Survey

The Phase II survey is a global survey of a set of PDT chambers mounted on each piece of the muon toroid magnet with respect to each other. In this survey, the location of all the bushing holes and tooling balls are tied to the previously established control points defined in the D0 global coordinate system. The Laser Tracker and the BETS system were used to establish the control points. Phase II survey is currently in progress using the V-STARS system. The required accuracy for the Phase II survey is specified as better than 0.5 mm.

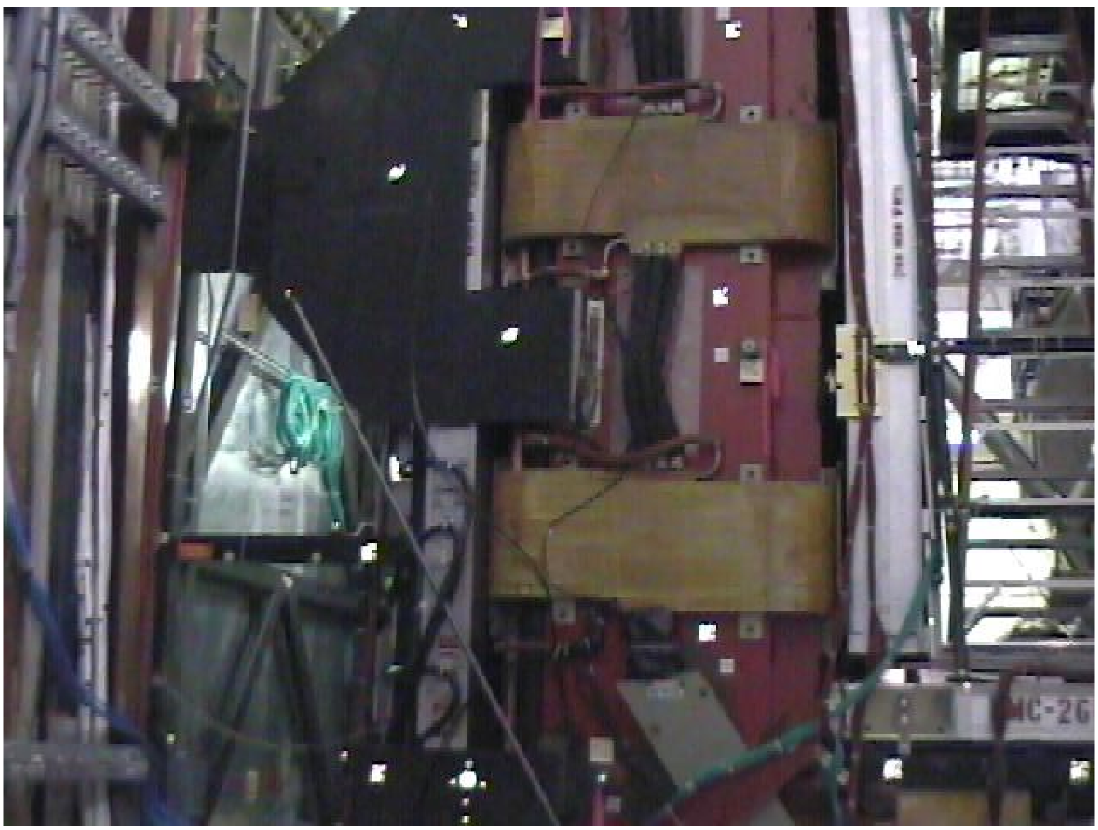

Figure 17. PDT Phase II Survey

4.9.2.2 MDT Survey

The assembled MDT octants are assembled into planes and mounted into the D0 detector. After the octants have been mounted, the relative position of all octants of one plane will be measured relative to each other and the reference control markers on the EF iron and the EMC trusses. In this survey, the location of all bushing holes are tied to the previously established control points defined in the D0 global coordinate system. The Phase II survey will be done with the V-STARS system. The required accuracy for the Phase II survey is specified as better than 0.5 mm.

Figure 18. MDT Phase II Survey

4.9.2.3 Pixel Counter Survey

The assembled Pixel Counter octants are assembled into planes and mounted into the D0 detector. After the octants have been mounted, the relative position of all octants of one plane will be measured relative to each other. The accuracy for locating the Pixel counter octant position is ±2.0 mm. In this survey, the location of all bushing holes are tied to the previously established control points defined in the D0 global coordinate system. The Phase II survey will be done with the V-STARS system. The survey data will be used for the final trigger tables and off-line data analysis.

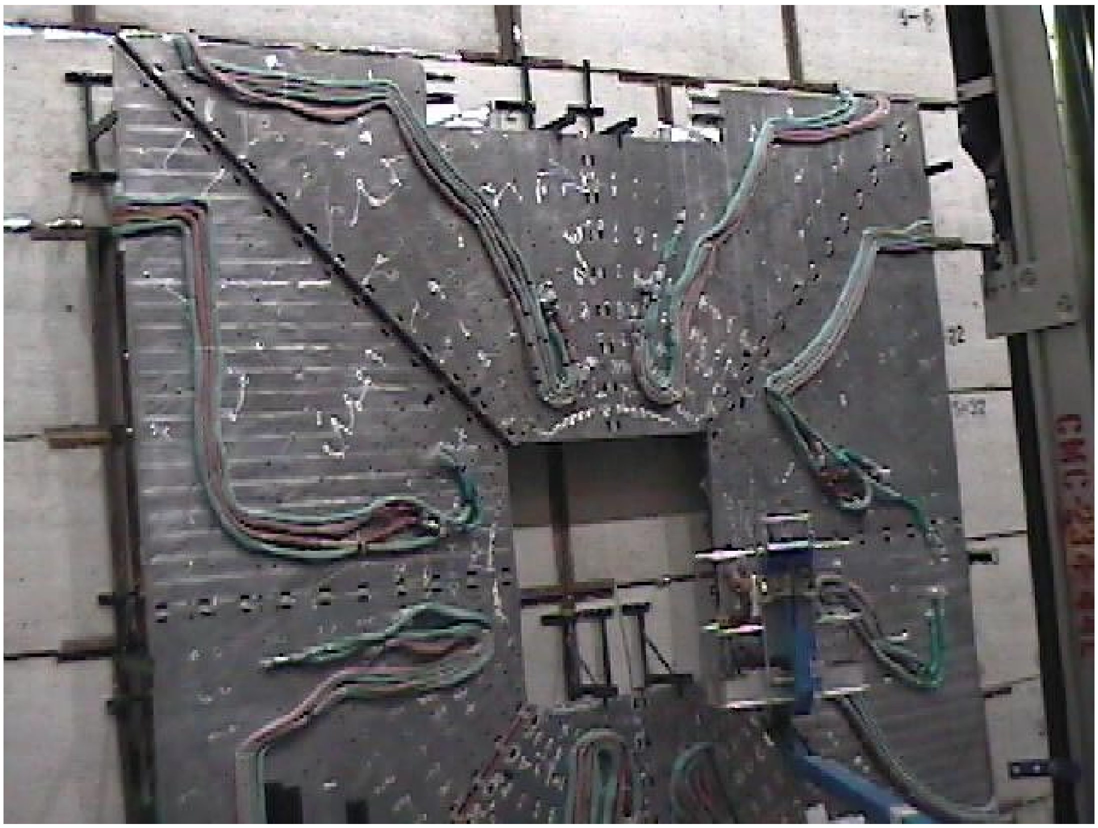

Figure 19. Pixel Phase II Survey

4.9.3 Phase III Survey

4.9.3.1 PDT Survey

The Phase III survey is the final measurement, made in the collision hall, which references the position of the groups of PDT chambers relative to each other and to the other detector systems. The Phase III survey must be repeated with each opening/closing of the detector. A quick analysis of the survey data is required so that the most current PDT chamber positions can be used in the software trigger and reconstruction [3]. The survey method to be used depends of the accessibility space constraints at the time of survey. The required accuracy for the Phase III survey is specified as better than 0.5 mm.

Figure 20. EMC Truss and Shielding Survey

4.9.3.2 MDT Survey

The Phase III survey is to determine the position of each octant in the collision hall. Since the octants are covered up in the collision hall, the survey is done by measuring to the points on the EF toroid and the EMC trusses. This survey will be repeated after each toroid magnet opening. The Phase III survey will be done with the V-STARS system. The required accuracy for the Phase III survey is specified as better than 0.5 mm.

4.9.3.3 Pixel Counter Survey

The Phase III survey is used to determine the position of each octant in the collision hall. This survey will be repeated after each toroid magnet opening and/or pixel counters plane movement to get access to the MDT planes. The survey for the pixel movement will only be done a few times to check repeatability but not every time [7]. The Phase III survey will be done with the V-STARS system. It is planned to have electronic monitoring of the location of the EF toroids, CF toroid, and EMC trusses so that surveying will not be necessary after the first few surveys [7]. The required accuracy for the Phase III survey is specified as better than 2.0 mm.

5. CONCLUSIONS

The upgrade of the D0 detector for Tevatron Run II have been described. The D0 detectors described are the Calorimeter, the Solenoid Magnet, the Central Fiber Tracker, the Forward Preshower, and the Muon Systems. The upgrade has three layers, A, B, and C. Contained in these layers to be surveyed are the PDT chambers, MDT octants, and the Pixel Counters octants. The survey of the Muon detector is done in three phases (Phase I, II, III). The required survey accuracy for all surveys is specified as better than 0.5 mm. Three different surveying methods are used for the survey, the Laser Tracker, the BETS, and the V-STARS systems. The survey of the Calorimeter, the Solenoid Magnet, the Central Fiber Tracker, the Forward Preshower have been completed. Phase I survey of the Muon Systems have also been completed. Currently in progress are the Phase II survey of the Muon Systems. The upgrade of the D0 muon detector is expected to be fully commissioned in September, 2000.

6. ACKNOWLEDGMENT

I would like to thank all the members of the Alignment and Metrology group that participated in the survey of the D0 detector.

7. REFERENCES

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